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SPEECH PERCEPTION DEVELOPMENT IN LANGUAGE-IMPAIRED CHILDREN: A 4-YEAR FOLLOW-UP STUDY

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A group of specifically language-impaired (SLI) children was compared with a matched group of non-SLI children (i.e., children displaying normal language) on tests of speech perception and language ability. The tests were administered longitudinally at times separated by an interval of 4 years. Initially (i.e., Time 1), the groups differed significantly in discrimination, sequencing, and rate processing of and serial memory for synthesized /bɑ/ and /dɑ/ stimuli. At Time 1, age effects were also observed among both groups of children. That is, performance improved as a function of increased age. At follow-up (i.e., Time 2), performance was at or near ceiling for subjects in both groups, indicating that perceptual development occurred in both groups of children. Results are discussed in relation to the hypothesis that perceptual deficits play a causal role in specific language impairment.

Children who are specifically language impaired (SLI) are characterized as having significant deficits in production and comprehension of language, yet they are of normal nonverbal intelligence (Benton, 1964). They have normal hearing and are progressing within normal limits in behavioral and emotional development. Auditory perceptual deficits have been hypothesized by some investigators as the cause of language and learning impairments in such children (Aten & Davis, 1968; Benton, 1964; Eisenson & Ingram, 1972; Hardy, 1965; Lowe & Campbell, 1965; Tallal, 1975; Tallal & Piercy, 1973, 1974). Stark and Tallal (1980, 1981a, 1981b; Tallal & Stark, 1981a, 1981b) have reported statistically significant differences between a sample of young SLI children and non-SLI children (i.e., children displaying normal language) on tests of verbal and nonverbal auditory perception and also on tests of visual, temporal and tactile perception. Other investigators have argued that auditory perceptual deficits are secondary to language impairments (e.g., Morehead & Ingram, 1973; Rees, 1973). According to these latter investigators, the causes of language impairment are more directly related to subtle cognitive, linguistic, and/or representational deficits.

One question that may be asked about perceptual deficits in SLI children is whether those deficits persist during childhood. In particular, better understanding of the relationship between language disabilities and perceptual deficits might be approached through longitudinal testing, using repeated measures of speech perception and linguistic abilities in SLI children. The study reported here represents some of the results of such a longitudinal study of SLI children and children displaying normal language. The initial (i.e., Time 1) testing of the children was conducted by Stark and Tallal (1980). In the Time 1 cross-sectional sample, age-related effects on speech perception tasks were evident in the performance of both the non-SLI and SLI children (Tallal & Stark, 1981a; Tallal, Stark, Kallman, & Mellits, 1980). Older SLI and non-SLI children performed more accurately and were able to attempt more difficult tests than their younger counterparts (Stark & Tallal, 1980). Age effects at Time 1 may, however, represent sampling error rather than developmental differences. For example, the results for the SLI children may have arisen due to the absence of adequate psychometric tools for selecting children such that speech and language were equally impaired across age. Older children might have been less impaired in language abilities. In order to determine whether speech perception develops in SLI children and to evaluate further the role of speech perception in the language development of SLI children, many of the original children from the Stark and Tallal (1980) study were relocated and retested, 4 years after initial testing, on the speech perception tests that had earlier best discriminated between the two groups of children.

At Time 2, the specific experimental questions addressed were, Would the age effect in speech perception, observed in the cross-sectional sample, be observed in the performance of individual children tested longitudinally? If the SLI children were able to progress perceptually, what would be the extent of their improvement? and Could evidence be obtained, based on performance across time, to support or reject the hypothesis that perceptual deficits in speech processing play a critical role in specific language impairment?

The speech perception tests administered at Times 1 and 2 came from the Repetition Method procedure devised by Tallal and Piercy (1973, 1974). The procedure was designed to investigate disorders of discrimination, sequencing, and rate processing of and serial memory for, speech and nonspeech auditory stimuli. Subtests of the procedure are administered in order of increasing diffi-

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culty. In order, they require children to (a) detect a signal (Detection subtest), (b) perform two-alternative forced choice classification (Association subtest), (c) classify two different signals in the same order as they are presented when the interstimulus interval (ISI) is fixed (Sequencing subtest) or variable (Rate Processing subtest), and (d) reproduce the sequence of signals that are presented in trains of three to seven (Serial Memory subtest).

On the basis of Time 1 testing, Tallal and Stark (1981a) suggested that SLI children "seem to have most difficulty responding to stimuli that both (1) incorporate acoustic cues that are brief, and (2) are followed in rapid succession by other acoustic cues" (p. 573). Since the signals /bɑ/ and /dɑ/ had been the most difficult overall for the SLI children at Time 1, and since speech as opposed to nonspeech auditory or visual perception was of greatest interest in relation to language development, these same stimuli were employed at Time 2.

The /bɑ/ and /dɑ/ stimuli chosen for Time 2 testing were the same two-formant synthetic stimuli employed at Time 1. The formant transitions signaling the /b/-/d/ distinction were 40 ms in length. In order to perform successfully on all the subtests beyond Detection, the child must be able to make use of the 30 ms of distinctive information in the formant transitions. In addition, the child must be able to remember the correct association between stimuli and response categories (i.e., response buttons). The associations between stimulus and response alternatives are demonstrated and practiced in the Association subtest. The Sequencing subtest additionally requires the child to reproduce the order of two stimuli. This subtest is both a preparation and a control for the Rate Processing subtest. This latter subtest evaluates directly the effect of shortening the duration of the ISI. If the presentation rate of brief acoustic characteristics is critical for SLI children, a significant decrement in performance can be expected between the fixed and variable ISI subtests. Finally, the Serial Memory subtest is included in order to evaluate the span of short-term memory.

Previous research has not investigated whether perceptual deficits are age related in SLI children. Arguments in favor of the hypothesis that perceptual deficits are causal in specific language impairment all imply that these deficits are associated with neurologic differences that are not susceptible to developmental change. The data from Time 1 suggested, to the contrary, that SLI children's speech perception improves with age. The longitudinal design of this study made it possible to investigate the strong hypothesis that perceptual deficits in SLI children persist during childhood. This hypothesis predicts that at Time 2 the SLI children would continue to have difficulty performing the Association, Sequencing, Rate Processing, and Serial Memory subtests.

METHOD

Subjects

In the original project there were 35 SLI and 36 control children. At Time 2, 29 SLI and 14 control children were relocated and agreed to participate again. At Time 2, the distribution of SLI children was 8 eight-year-olds, 4 nine-year-olds, 5 ten-year-olds, 8 eleven-year-olds, and 4 twelve-year-olds. At Time 2, the distribution of non-SLI children was 5 nine-year-olds, 5 ten-year-olds, and 4 eleven-year-olds. A detailed description of the original selection criteria and procedures used at Time 1 to identify these children is provided in Stark and Tallal (1981b). These extensive selection procedures yielded at Time 1 a group of SLI children and a group of matched non-SLI children who shared the following characteristics:

1. Hearing was within normal limits for pure tones, and speech reception thresholds were no greater than 25 dB for both the right and left ears. None of the children had a history of recurring otitis media.
2. Neurologic histories were normal, and the children did not exhibit frank neurologic deficit. All were without a history of neurologic deficit, trauma, or illness.
3. None of the children exhibited emotional or behavioral problems requiring intervention.
4. All children had normal nonverbal intelligence scores (WPPSI, Wechsler, 1963; WISC-R, Wechsler, 1974). The control children had verbal scores within 15 points of their performance scores. The SLI children had verbal scores less than their performance scores.

At Time 1, each child was given a battery of speech and language tests.[1] A language age (LA) score was derived for each child. LAs were the mean of the age-related scores obtained on standardized tests of receptive and expressive language. SLI children were required to have an overall LA at least 12 months lower than chronological age (CA). Receptive LA was required to be 6 months below performance mental age on the appropriate intelligence test (WISC-R or WPPSI, depending on the child's age), and expressive LA was required to be 12 months below performance mental age. Control group children were required to have LAs and reading skills that were no more than 6 months behind their CA and performance mental age. Children were included in the non-SLI control group only if articulation errors were within normal limits for their CA, whereas SLI children with articulation errors were included provided that their level of articulation skill was no more than 6 months below their expressive LA.

At Time 2, the following tests were administered: (a) WISC-R (Wechsler, 1974); (b) Peabody Picture Vocabulary Test (Dunn, 1959); (c) Token Test (DeRenzi & Vignolo, 1962); (d) Northwestern Syntax Screening Test (Lee, 1969); (e) Auditory Association, Grammatic Closure, and Auditory Reception subtests of the Illinois Test of Psycholinguistic Abilities (Kirk, McCarthy, & Kirk,

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[1] Language tests administered at Time 1 were: the Token Test (DeRenzi & Vignolo, 1962), the Northwestern Syntax Screening Test (Lee, 1969), subtests of the Illinois Test of Psycholinguistic Abilities (Kirk, McCarthy, & Kirk, 1968), Developmental Sentence Analysis (Lee, 1974), the Test for Auditory Comprehension of Language (Carrow, 1973), and the Templin-Darley Test of Articulation (Templin & Darley, 1960).

1968); (f) Boston Naming Test (Kaplan, Goodglas, & Weintraub, 1978); (g) Spencer Memory for Sentences Test (Spencer, 1958); (h) Templin-Darley Test of Articulation (Templin & Darley, 1960); and (i) the Gates McGinitie Vocabulary and Comprehension subtests (Gates & McGinitie, 1972). A hearing screening was also administered and revealed that hearing was within normal limits for all the children.

Stimuli

Stimuli for speech perception testing were two-formant consonant-vowel (CV) syllables, /bɑ/ and /dɑ/, synthesized at Haskins Laboratories. Syllable duration was 250 ms. The initial 45 ms of each syllable was comprised of a 5-ms noise burst followed by a linear formant transition. The first formant for both /bɑ/ and /dɑ/ began at 562 Hz and rose to a steady state value of 769 Hz. Initial second formant ($F2$) for /bɑ/ was 1,075 Hz and for /dɑ/ was 1,541 Hz. The $F2$ steady state value was 1,232 Hz. Fundamental frequency was held steady at 114 Hz and then fell linearly to 74 Hz during the final 50 ms of each stimulus. During that same interval amplitude dropped by 28 dB.

Procedure

The procedure followed the repetition method developed by Tallal and Piercy (1973, 1974) that was employed when these children were tested at Time 1. The method is designed to minimize verbal instruction. Each task is first demonstrated by the experimenter. Failure to reach a specified criterion on a subtest results in termination of testing. The rationale for this protocol is that each test is assumed to require the abilities of the previous test(s). A child was considered to have mastered a task by performing correctly on a specified number of trials. The number of trials to criterion required to assure a low probability of chance correct performance was obtained using the normal approximation to the binomial distribution (Siegel, 1956).

The procedure begins by training subjects to press one button of a two-button response box in response to one of two possible stimuli (Detection subtest). Then the subjects receive training for the second of the two stimuli corresponding to the second button. Separate sets of trials for each button continue until the child has made 10 correct responses out of 15 trials for each stimulus (button). The probability of chance success across 30 trials is $p < .05$. Detection is basically a training procedure that provides experience hearing the stimuli and pushing the designated response buttons.

In the next subtest (Association subtest), the stimuli are presented in random order. The experimenter demonstrates eight trials and then shows the child which button will be the next correct response. The criterion for success on this subtest is a correct response on 20 out of 24 trials. If a child fails to achieve this level, 24 more trials are administered. Success on the first or second set of 24 allows the child to continue in this procedure. The probability of chance success is $p < .001$ for a set of 24 trials. The 24 trials are administered twice, because the task is primarily for training two-alternative forced choice responses. By allowing the child two opportunities to succeed, the procedure assures that children are given an adequate opportunity to demonstrate their abilities.

If the child is successful on the Association subtest, the Sequencing subtest is presented next. In the Sequencing subtest, 24 stimulus pairs are presented, each separated by a fixed 500-ms ISI. The subject is required to press the appropriate buttons in the same temporal order as that in which the items are presented. The pairs include both *same* (/bɑ-bɑ/, /dɑ-dɑ/) and *different* (/bɑ-dɑ/, /dɑ-bɑ/) combinations. If the child makes a total of 14 errors in the first 12 pairs, counting one error for each incorrect button press, subsequent tasks are not presented. If fewer than 14 errors are made, the child is again presented with 12 stimulus pairs. The criterion of fewer than 14 errors is then imposed across the 24 pairs (i.e., a minimum of 34 correct responses is required to meet criterion). The probability of a child reaching criterion by chance is $p < .003$. The Sequencing subtest with fixed ISI is training and a control for the next subtest with variable ISI.

Succeeding on the fixed ISI trials allows the subject to go on to the Rate Processing subtest which employs the same stimulus pairs and response; however, in this subtest the ISI is varied. Eight trials at each of three ISIs—10, 70, and 500 ms—are presented in random order. Subjects are tested on 24 stimulus pairs. If 14 errors are made (34 correct responses required), testing is discontinued. The probability of chance success is $p < .003$ for the set of 24 stimulus pairs.

In the last subtest, Serial Memory, the ISI is 500 ms, but the number of stimuli per trial is increased systematically across levels from three items to seven. At each level, five stimulus combinations are tested. If the child makes errors on fewer than two of the five stimulus trains, testing is continued to the next level of Serial Memory trials (i.e., four out of five responses must be correct to meet criterion at each level).

In the event that a child fails the Association subtest, a "go no-go" procedure is administered in order to determine whether the failure was due to the child being unable to discriminate between the stimuli or unable to learn the association task. Only one response button is provided for the go no-go procedure. First, the child must detect the presentation of /bɑ/ and push the button following each presentation. Second, /bɑ/ is presented alternating in random order with a noise stimulus. The child is shown that responding should continue as before to the /bɑ/ but be withheld following the noise. This is a control for the final test in the go no-go procedure in which /bɑ/ is presented in random order with /dɑ/, and once again responding is to /bɑ/ only. If the child is successful when the /bɑ/ alternates with noise but fails when the two speech stimuli are presented, it is inferred that the child was unable to discriminate between the synthetic speech stimuli.

All perceptual tasks were administered by the first and second authors and a postdoctoral clinical fellow. The second author had extensive experience administering the procedure at Time 1, and she instructed the Time 2 experimenters. All language testing was done as part of the experimental protocol. In addition to the above experimenters, a speech-language pathologist was employed to assist in administering language tests. This speech-language pathologist worked under the second author's supervision. Completion of the entire protocol required approximately 6–7 hr per child. Children were tested individually in a quiet room in their school. Testing never exceeded 1 hr per session and was spaced at approximately weekly intervals. The repetition method was administered within a single session.

RESULTS

It is important to report first that 23 of the 29 children in the follow-up study who were identified as language impaired at Time 1 were also language impaired at Time 2. The criteria for considering a child to be SLI at Time 2 were the same as at Time 1: (a) receptive LA at least 6 months below performance mental age based on (WISC-R or WPPSI-I)[2], (b) expressive LA at least 12 months below performance mental age (WISC-R), and (c) overall LA at least 12 months below chronologic age and performance mental age. Three of the 6 children reclassified as normal in language at Time 2 were aged 8 years, 2 were aged 9, and 1 was aged 10.

Table 1 is a summary of mean chronologic age, full scale IQ, performance IQ, verbal IQ, and LA age obtained at Times 1 and 2.[3] A mean LA is not reported for the non-SLI children because they scored at ceiling on most of the language tests. Table 1 shows that as a group the SLI Children achieved normal scores on the performance part of the intelligence test. However, their language abilities at Time 2 were clearly below what would be expected of normally developed children of the same nonverbal intelligence. The non-SLI children showed somewhat elevated performance intelligence scores (as had been the case at Time 1), and their performance on most of the language tests was at ceiling.

The results in Table 1 show that although the mean LA of SLI children was depressed relative to chronologic age, the children had progressed in their language abilities (for more details see, Stark et al., 1984). However, expressive language was more impaired than receptive language, as it had been at Time 1 also. These results show that the perceptual deficits observed at Time 1 did not prevent the SLI children as a group from progressing in language development. The relationship between the results of language testing and speech perception tests is discussed in more detail in the discussion.

Speech Perception Tests

All the children completed the Detection subtest without errors. Since they had also passed this test at Time 1, and since it serves mostly to familiarize subjects with the response mode, there is no need to further discuss this result.

Most children, non-SLI and SLI, were highly successful on the next subtest, Association. It will be recalled that this is a two-alternative forced choice procedure in which the child must remember the correct correspondence between stimuli and response buttons. Being able to reach criterion implies the ability to discriminate and correctly categorize stimuli.

At Time 2, 24 out of 29 SLI children reached criterion on Association. In contrast, at Time 1, 19 from this group of children failed. Since children had two opportunities to achieve the criterion of 20 out of 24 correct, we may ask whether criterion was reached after few or many errors. Across the SLI group, most successful children were also highly accurate. Of the 29 SLI children, 18 made one or no errors, 5 made between two and four errors, and only 1 child made six errors.

The performance of non-SLI children on the Association subtest at Time 2 was similar to their performance at Time 1; that is, 12 out of 14 children reached criterion. No errors were made at Time 2 by successful children.

Of interest is whether the SLI children could be distinguished from the non-SLI children on the basis of their Association results. In comparing the groups, we first observed that among the SLI children, 6 had progressed sufficiently in their language abilities so that they were no longer considered SLI at Time 2. If those 6 reclassified SLI children are removed for the purpose of calculating the percentage of failures in each of the Time 2 groups, the results are 12% and 14%, SLI and non-SLI, respectively. These numbers indicate that the groups could not be distinguished on the basis of their ability to perform to criterion on the Association subtest. There were more errors to criterion among the SLI children; however, they were committed by a small number of children and are not representative of the overall excellent performance of SLI children at Time 2.

When a child failed the Association subtest, the go no-go procedure was employed in order to determine the possible cause of failure. If a child performed to criterion on the go no-go procedure, it could be inferred that the child was able to discriminate /bɑ/ from /dɑ/ and that failure on the Association subtest was attributable to inability to adequately perform the required response.

The 3 Time 2 children still classified as SLI who failed to reach criterion on the Association subtest also failed to

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[2] Performance mental age was calculated as at Time 1 (i.e., the child's chronologic age in months was multiplied by his or her IQ/100).

[3] Means and standard deviations are calculated in terms of the groups as they were selected at Time 1 and do not reflect the reclassifications of 6 SLI children at Time 2. Note, however, that data are presented only for subjects who were tested at both Times 1 and 2.

TABLE 1. Mean chronologic age, intelligence quotient, and language age at Times 1 and 2 for SLI and non-SLI children.

Subject group	*Chronologic age*	*Intelligence quotient* *Full scale*	*Performance*	*Verbal*	*Language*[a] *age*
SLI children (n = 29)					
Time 1	6:6	89 (6.8)	98 (7.9)	82 (9.0)	4:10 (0:10.9)[b]
Time 2	10:3	94 (14.3)	102 (15.9)	87 (9.2)	7:9 (0:14.3)
Non-SLI children (n = 14)					
Time 1	6:11	110 (6.4)	105 (7.9)	112 (14.2)	7:10 (0:11.1)
Time 2	10:7	120 (6.4)	117 (9.5)	122 (13.2)	–

Note. Standard deviations are in parentheses.
[a]Mean of expressive and receptive language age scores in years:months. [b]Standard deviation in years:months.

perform to criterion on the /bɑ/-/dɑ/ portion of the go no-go procedure. Since these children were successful when /bɑ/ alternated randomly with noise, we can infer that these subjects were unable to discriminate /bɑ/ from /dɑ/. Subject 97, who was reclassified as non-SLI, failed the Association subtest and performed on the go no-go procedure similarly to the SLI children. Subject 89, who was also reclassified as non-SLI but failed the Association subtest, successfully completed go no-go testing. He spontaneously commented that "it was the *bas* and not the *das*" that were the signal to press the response button. Thus it seems that Subject 89 was unable to provide the correct response alternative but could discriminate between the stimuli.

The 2 non-SLI children who failed the Association subtest at Time 2 (Subjects 35 and 57) failed because they could not discriminate between the syllables. The go no-go procedure was administered to these 2 children. Both could perform adequately when the stimuli were /bɑ/ alternating with noise, but neither was able to perform to criterion when /bɑ/ and /dɑ/ were presented.[4]

Tables 2 and 3 show raw scores for the fixed ISI Sequencing and variable ISI Rate Processing subtests. Scores are given for Times 1 and 2 for the SLI and non-SLI children, respectively. The code NA (i.e., not available) in the tables signifies that the child failed on the Association subtest and therefore was not tested on subsequent tests. An R follows the identification number of SLI subjects who were reclassified at Time 2 as non-SLI. Individual raw scores are given because the number of children in each age group is small, and because a clear understanding of the results is achieved most readily if information about individual performances is preserved.

Examination of the results at Time 2 for the fixed ISI Sequencing subtest (see Tables 2 and 3) reveals that all but one of the children tested exceeded the performance criterion of 34 out of 48 correct responses (i.e., <14 incorrect responses; $p < .003$, by the binomial test). The level of criterion required to be successful implies that the children understood the task, could discriminate the stimuli, and could accurately reproduce the order in which the stimuli were presented. The one subject who passed the Association subtest but did not succeed on fixed ISI Sequencing was an 11-year-year-old SLI child. This child, Subject 111, was not tested further. Thus, with one exception, if a child was able to pass the Association subtest, that child was also able to pass fixed ISI Sequencing, regardless of language ability.

A comparison of the number of errors on fixed ISI Sequencing among SLI children aged 9, 10, and 11 years with those of the non-SLI children of the same ages readily shows more errors among the SLI group (i.e., 39 as opposed to 0 errors). Interpretation of these errors is not straightforward, however, because they do not represent well the overall excellent performance of the SLI group. Four children (Subjects 128, 111, 26, and 51) account for all but two errors (Subject 101). (Two errors were made by Subject 99 who was reclassified as non-SLI and not included in this comparison.) Subjects 128 and 51 improved between test times, but not as much as their age mates. Subjects 111 and 26 showed a decline. However, Subject 111 was the only one among the 4 who failed to achieve the criterion level of performance. For none of these subjects can errors be attributed to failure to discriminate among stimuli because all passed criterion on the Association subtest. Errors committed by Subjects 128, 26, and 51 cannot be attributed to failure to understand the procedure because they exceeded the performance criterion. Although their errors may be the result of significant individual differences between them and the other children, we can at this time only interpret their

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[4] Based on these children's comments, it appeared that they did not recognize the /bɑ-dɑ/ stimuli as speech. Nevertheless, since testing was conducted without the use of verbal labels, this apparent absence of phonetic perception need not have influenced performance. Tasks required only the ability to discriminate between stimuli and use some distinctive characteristics to pair each stimulus with one or the other of the response buttons. Verbal labels may facilitate success, but it should be noted that tones were employed successfully with these procedures at Time 1 (see Stark & Tallal, 1980).

TABLE 2. Number of incorrect responses for fixed ISI Sequencing and variable ISI Rate Processing subtests of specifically language-impaired children.

Subject			*Fixed ISI Sequencing*		*Variable ISI Rate Processing*	
Age	*ID*	*Sex*	*Time 1*	*Time 2*	*Time 1*	*Time 2*
12 years:						
	39	M	0	0	4	0
	63	F	NA	0	NA	0
	115	M	NA	0	NA	0
	123	M	NA	1	NA	0
11 years:						
	135	M	NA	0	NA	2
	128	M	NA	9	NA	8
	111	M	9	F[a]	F[a]	NA
	76	M	8	0	13	0
	19	M	0	0	0	2
	21	M	1	0	0	4
	26	M	0	6	2	11
	32	M	0	0	0	0
10 years:						
	97(R)[b]	M	NA	NA	NA	NA
	116	M	NA	0	NA	0
	101	F	NA	2	NA	2
	82	M	11	0	12	1
	67	M	NA	NA	NA	NA
9 years:						
	129	M	NA	0	NA	2
	99(R)[b]	M	NA	2	NA	0
	51	M	NA	6	NA	4
	68(R)[b]	M	0	0	4	0
8 years:						
	94	F	NA	4	NA	13
	89(R)[b]	M	NA	NA	NA	NA
	134(R)[b]	M	NA	0	NA	2
	78	M	NA	0	NA	2
	59	F	NA	NA	NA	NA
	105	F	NA	NA	NA	NA
	58	F	NA	2	NA	0
	25(R)[b]	M	5	2	11	2

Note. NA = not available; the child failed to reach criterion on the previous subtest and was therefore not tested further.

[a] Failed to reach criterion. [b] An R following the subject's identification number indicates reclassification at Time 2 as no longer language impaired.

errors as uncontrolled performance variables in the context of these procedures.

All the children, non-SLI and SLI, who were subsequently tested on the variable ISI Rate Processing subtest were able to reach the performance criterion of 34 out of 48 correct ($<$14 incorrect responses; $p < .003$, binomial test). This result implies that neither brevity nor variability of ISI was a significant factor for either group of children.

The variable ISI Rate Processing subtest is critical in evaluating the children's perceptual abilities in relation to the suggestion that their impairments are most severe for brief acoustic cues that occur in rapid succession (Tallal & Stark, 1981a). A repeated measures t test for the Time 2 SLI children's scores (excluding children reclassified as non-SLI) showed a statistically significant difference in errors between the fixed ISI Sequencing and the variable ISI Rate Processing subtests ($t(19) = 1.8$, $p < .05$, one-tailed). However, percentage errors were small for both conditions—6% of the total number of responses for fixed ISI and 10% for the variable ISI Rate Processing. Examination of the distribution of errors as a function of ISI showed them to be distributed approximately equally among the three different ISI durations. Two of the SLI children accounted for approximately half of the total increase in error, but for these 2 children, errors were not monotonically related to ISI, as most were made at 70 and 500 ms. Five of the SLI children made fewer errors in the variable than in the fixed condition.

As was the case for fixed ISI Sequencing, it is not possible to attribute the errors on variable ISI Rate Processing to auditory processing deficits. In order to do

TABLE 3. Number of incorrect responses for fixed ISI Sequencing and variable ISI Rate Processing subtests of non-SLI children.

Subject			*Fixed ISI Sequencing*		*Variable ISI Rate Processing*	
Age	*ID*	*Sex*	*Time 1*	*Time 2*	*Time 1*	*Time 2*
11 years:						
	109	M	0	0	0	0
	77	M	0	0	1	0
	84	F	0	0	2	0
	45	F	0	0	2	0
10 years:						
	56	M	0	0	0	0
	106	F	0	0	0	0
	35	M	8	NA	9	NA
	3	F	NA	0	NA	1
	8	M	1	0	0	0
9 years:						
	57	M	NA	NA	NA	NA
	83	F	0	0	1	0
	91	M	0	0	0	0
	102	M	0	0	0	0
	103	F	10	0	13	0

Note. NA = not available; the child failed to reach criterion on the previous subtest and was therefore not tested further.

so, it would have been necessary to have obtained a systematic error pattern related to the ISI variable. Thus error must again be attributed to uncontrolled performance factors. In general, therefore, it may be concluded that the variable ISI Rate Processing subtest failed to reveal at Time 2 the same auditory processing deficit observed at Time 1. These results are discussed further below.

Serial Memory scores are shown in Table 4 for both groups of subjects at Times 1 and 2. Scores tabulated indicate the longest Serial Memory sequence for which the child was successful. That is, a score of 4 means that the child was able to reproduce at least two out of the five trains of four syllables but failed to perform adequately when there were five syllables in a series. At Time 1, only 9 of the 29 SLI children were tested. At that time, their scores ranged between failure (F) on trains of three syllables to success on trains of five. At Time 2, the majority of SLI and non-SLI subjects achieved scores between 4 and 6. Serial Memory scores at Time 2 were not correlated with age for either group of children. However, with only a few exceptions, children in both groups showed improved performance across Times 1 and 2. Only 1 child (Subject 56) performed at a ceiling level (i.e., seven syllables) on the Serial Memory subtest.

DISCUSSION

During the 4-year interval between testing times, most of the SLI children progressed from being unable to learn the Association subtest to being able to complete the subtests through variable ISI Rate Processing at or near ceiling level. The SLI children did not perform at ceiling on the Serial Memory subtest but neither did their controls.

On the basis of these results, the answer to our first experimental question is that there was perceptual development among the language-impaired children. Also, these results suggest that the age effects observed at Time 1 were genuine and not attributable to sampling error. In answer to our second question, the extent of perceptual development in either language group remains unknown. It is not possible to infer the level of Time 2 perceptual functioning because the tests were essentially too easy for most of the SLI and non-SLI children at that time. Furthermore, the low error rate does not lend itself to meaningful interpretation of individual differences.

The third experimental question was concerned with finding evidence to support or reject the hypothesis that perceptual deficits are causal in specific language impairment. At both Times 1 and 2, the procedures tested the suggestion made by Tallal and Stark (1981a) that SLI children have most difficulty responding to stimuli that incorporate brief acoustic-phonetic cues and are presented in rapid succession. This difficulty was considered critical by Tallal and Stark, since there is evidence that normal speech perception depends on extracting rapidly changing spectral patterns associated with consonants (e.g., Kewley-Port, Pisoni, & Studdert-Kennedy, 1983; cf., Blumstein & Stevens, 1980).

The variable ISI Rate Processing subtest tests directly the role of stimulus presentation rate with stop CV syllables. At Time 2, the majority of SLI children were successful on Rate Processing. Even at the youngest age,

TABLE 4. Serial memory scores of SLI and non-SLI children.

	SLI			*Non-SLI*		
Age	*ID*	*Time 1*	*Time 2*	*ID*	*Time 1*	*Time 2*
12 years:						
	39	3	4			
	63	NA	5			
	115	NA	5			
	123	NA	5			
11 years:						
	135	NA	5	109	5	4
	128	NA	3	77	4	5
	111	NA	NA	84	4	5
	76	F[a]	5	45	5	5
	19	4	6			
	21	4	4			
	26	5	4			
	32	3	6			
10 years:						
	97(R)[b]	NA	NA	56	5	7
	116	NA	4	106	5	6
	101	NA	4	35	3	NA
	82	F[a]	4	3	NA	6
	67	NA	NA	8	4	4
9 years:						
	129	NA	6	57	NA	NA
	99(R)[b]	NA	5	83	4	5
	51	NA	4	91	3	4
	68(R)[b]	4	5	102	4	6
				103	3	5
8 years:						
	94	NA	NA			
	89(R)[b]	NA	NA			
	134(R)[b]	NA	5			
	78	NA	5			
	59	NA	NA			
	105	NA	NA			
	58	NA	4			
	25(R)[b]	F[a]	6			

Note. The score is the number of stimuli in the longest trains for which the child was successful. NA = not available; the child did not reach criterion on a previous subtest and was therefore not tested further.

[a]F = failed on serial memory 3.

[b]An R in parentheses following the subject's identification number indicates reclassification at Time 2 as normal language.

if a child was administered the test, it was completed successfully (see Table 2). At the same time, most SLI children remained clearly language impaired. Therefore, considering Time 2 results alone, we could not conclude that specific language impairment in older children is caused by perceptual deficits in rapid rate processing of phonemes. The results of Time 2 testing suggest instead that SLI children beyond the age of 8 years do not have difficulties obtaining information about formant transitions from speech stimuli presented in rapid succession. However, it should be noted that the low obtained error rates may be indicative of a ceiling effect. An adequate test of the rate-processing hypothesis would require a task sufficiently difficult to produce a pattern of errors that is related to the stimulus parameters in a theoretically predicted manner. Although the Rate Processing subtest failed to reveal a relationship at Time 2 between language ability and speech perception, such relationships likely continue to exist but require more complex perceptual tasks to reveal them.

Also, from a developmental perspective, it is not possible at this time to reject the hypothesis that perceptual deficits are causal in specific language impairments. Language disabilities may result when inadequate processing of sensory information occurs during early childhood although the original processing deficit may no longer exist. The longitudinal results show that early perceptual deficits do not prevent language development. Language does develop in SLI children, however, more slowly than for children who display normal language.

These results do not allow us to reach a conclusion about the role of perceptual factors in specific language impairment. However, it is likely that questions framed about language impairment on the basis of simple dichotomies between, for example, language and perception presuppose inadequate models of both language comprehension and speech perception. Current models of language comprehension (e.g., Cole, Jakimik, & Cooper, 1980; Marslen-Wilson & Welsh, 1978) and speech perception (e.g., Klatt, 1979; Pisoni & Sawusch, 1975) explicitly include interactions between phonetic and phonologic processes and syntax, semantics, and lexical access. The comprehension of words in connected speech is modeled as a data-driven process (i.e., based on acoustic-phonetic input) that is guided by internal linguistic constraints. Experimental studies with language-normal children and adults suggest that these interactions, which Tyler and Marslen-Wilson (1981) call "the internal structure of processing events" (p. 400), are present at least by age 4–5 years in the normal child (Cole & Perfetti, 1980; Tyler & Marslen-Wilson, 1981).

Importantly for understanding SLI children, interactional models imply that deficits in perception can have effects on linguistic contraints and vice versa. For example, a child must learn the phonemic inventory and phonologic rules of the native language. Both vary across languages. Furthermore, phonemes and phonologic rules are not available to be learned on a purely statistical basis, that is, they cannot be derived by sampling speech stimuli without regard to meaning. Phonemes are phonemes because they signal differences in meaning between words. Children need words to learn phonemes and phonemes to learn words.[5] An adequate explanation for specific language impairment needs to take into account interactions among perceptual and linguistic processes.

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[5]This view is consistent with, for example, Klatt's (1979) model of acoustic-phonetic analysis and lexical access. Klatt suggests that "the earliest representation of words by an infant is probably in the form of a crude encoding of what appears on the [hard-wired?] neural spectrogram. Perhaps only a few of the most prominent spectral details within a word are remembered at first" (p. 308). New spectral details are filled in with development "but only when needed to differentiate between words" (p. 308).

The results of the Serial Memory subtest require some comment. They show no effects of age or language ability at Time 2, although virtually all the children improved between Times 1 and 2. Increases in the span of serial memory from two to approximately eight items between 2½ and 16 years of age are well documented for unimpaired children (Huttenlocher & Burke, 1976). It is not known why span increases with age. Huttenlocher and Burke (1976) tested unimpaired children between 4 and 11 years of age in order to determine whether span improves due to age-related increases in rehearsal during input or to subjects' active grouping of incoming sequences. Neither possibility was confirmed by their experiment. As an alternative, Huttenlocher and Burke offer an explanation that is relevant here. They point out that in studies of adults, memory span is affected by the acoustic confusability of stimuli. They hypothesize that "if the difficulty of identifying items varies with age it could be an important factor in the development of span" (1976, p. 21). According to this line of argument, the limit on span occurs during the process of identifying the input.

The important point raised by Huttenlocher and Burke is that serial memory span is not independent of stimulus identity. Thus, whenever SLI children have relatively greater difficulty identifying stimuli, they may be expected to evidence shorter serial memory spans. The results reported above suggest that when the SLI children are able to successfully identify the stimuli, serial memory span is no different from that of control subjects.

It is surprising that no serial memory age effect was observed among children in either group. The reason may be an intrinsic difficulty of the task. A nonverbal response was chosen so as not to bias the results against SLI children. However, the programming and rehearsal of motor sequences may itself consume memory processes and may limit serial memory span.

During the interval between Times 1 and 2, the SLI children received language intervention. The children's parents and schools were responsible for the duration and type of intervention. Since therapy was not controlled in the study, the results reported here cannot be interpreted with respect to clinical variables. Further research is required to determine whether longitudinal changes in speech perception of SLI children are brought about as a result of clinical intervention, and if so, what the significant factors may be.

GENERAL CONCLUSIONS

The results of this study suggest that early deficits in speech perception do not prevent SLI children from making progress in language development. These results do not provide support for attributing a causal role to *either* perceptual *or* linguistic deficits. It is likely, rather, that complex interactions between perceptual and cognitive/linguistic processes need to be understood in detail before the etiology and course of development in specific language impairment are understood.

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